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A Multipath Calculation of Surface-Generated Underwater Acoustic Ambient Vertical Directivity

A Paper Presented at the Second Joint Meeting of the Acoustical Societies of America and Japan, Honolulu, Hawaii, 18 November 1988

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PREFACE

This report was prepared under Project 638V11, Principal Investigator R.M. Kennedy (Code 3802). The work reported herein was performed as part of the Naval Underwater Systems Center Test and Evaluation Department Acoustic Range Initiative.

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19. ABSTRACT

A general calculation of the spatial correlation function due to a distributed acoustic source near the water surface has been done [W.A. Kuperman and F. Ingenito; J. Acoust. Soc. Am., 67, (1980) 1988-1996] using normal mode theory. In this paper a multiple ray path analysis is used to calculate the acoustic ambient vertical directivity function. Multipath propagation and ambient directional functions are physically intuitive concepts to underwater acoustic theory, and direct application of these notions has advantages in the interpretation of data. Existing procedures and computer code [H. Weinberg; J. Acoust. Soc. Am., 58, (1975) 97-109] were used to expand the received pressure field, from a distributed source, into a sum of terms interpreted as multiple propagation paths. Standard forms for the source function and a geometric transformation were used to convert the pressure field to a solid-angle density function. Surface roughness, bottom geoacoustic parameters, and sound velocity/depth profiles measured in the Tongue of the Ocean in The Bahamas, were used in the calculations to predict hydrophone array performance in that area. Directivity function versus elevation angle and frequency are displayed for observers above and below a surface duct. A path-by-path contribution to the vertical distribution of energy is discussed.

INTRODUCTION

This document is a transcript of the presentation given by Dr. Kennedy to the Second Joint Meeting of the Acoustical Society of America and the Acoustical Society of Japan on November 18, 1988.

Pages 2 through 8 contain the precis he orally presented, and pages 9 through 22 show the components of his display poster.

SLIDE 1

The space-time statistical description of the underwater ambient acoustic field has well-known scientific and sonar interest. Specification of the spatial form of the description takes on several different structures. One finds in literature references to spatial correlation functions, wavevector spectral density functions, and solid-angle spectral density functions. We chose the latter form for the present work because of the intuitive appeal of associating a direction of arrival with the ambient description. Thus the objective of this work is a calculation of the vertical directional-frequency spectra of the ambient acoustic field due to geophysical acoustic sources, the most common of which is agitation of the air-water interface. The motivation, and thus relevance, of this calculation is two-fold. Primarily the information is critical to the design of an acoustic antenna intended to optimally exploit a specific environment. The second purpose is to supply a model that can be useful in interpreting data from an existing array of hydrophones.

Multipath Calculation of the Acoustic Vertical Directional Spectra

OBJECTIVE

Theoretical Prediction of Vertical Directional-Frequency Spectra of Acoustic Ambient Due to Distributed Near-Surface Sources

RELEVANCE

- Basis for Acoustic Antenna Design
- Experimental Data Interpretation Tool

SLIDE 2

The problem is one in which we wish to calculate the directional spectra at a point in the underwater space caused by a distributed acoustic source of large geophysical extent. Diffuse surface-generated acoustic radiation has been modeled for many years as an infinite plane of radiating points parallel to the surface. In this plane the source elements have been modeled either as monopoles having a specified horizontal spatial correlation or as statistically independent sources having a specified vertical directivity. The radiation from this distributed source must then be propagated to the desired receiving location where a space-time statistical description is generated. The most general calculation of this kind has been done by Kuperman and Ingenito. They used a normal mode theory to handle the propagation and chose a spatial correlation function description of the acoustic field at the receiver location. In the present work we use a multiple ray path analysis to calculate directly the acoustic ambient vertical directivity spectral density. This approach has advantages in the physical interpretation of underwater acoustic data because multipath propagation and ambient directional functions are familiar concepts in underwater acoustic experimentation. The direct application of these concepts in a theoretical analysis is useful and is accomplished with no loss in generality. Surface roughness, bottom geoacoustic parameters, and arbitrary depth dependence of the acoustic phase velocity are incorporated by methods developed by Weinberg in the early 1970s. He expanded the received pressure field into a sum of terms interpreted as multiple propagation paths. Standard forms for the source function and a geometric transformation are used to convert the pressure field to a solid-angle density function.

Multipath Calculation of the Acoustic Vertical Directional Spectra

PROBLEM STATEMENT

Calculate Space-Time Statistical Character of the Underwater Acoustic Field Resulting from a Large Area Random Distributed Source

CURRENT APPROACH

- Kuperman and Ingenito, J. Acoust. Soc. Am., 67, 1980
- Calculates Spatial Correlation
- Normal Mode Theory Approach

ALTERNATE APPROACH

- Calculate Directional-Frequency Spectra
- Multipath Expansion (Eigenray) Approach

SLIDE 3

Although the calculations were done with a specific location in mind, that is, The Tongue of the Ocean in The Bahamas, quite general conclusions with regard to parameter dependence result from the study. The outcomes can be grouped in three categories. First is the position of the observer with respect to the thermocline. Quite dramatic changes in the directional spectra occur with a change in depth across the thermocline. Second are contributions to the directional spectra from energy arriving by the various paths. Third are changes in the directional spectra resulting from changes in the directional character of the sources.

Multipath Calculation of the Acoustic Vertical Directional Spectra

RESULTS

- Directional-Frequency Spectral Calculation
  - Sound Velocity Depth Effects
    - + Surface Duct
    - + Thermocline Position
  - Multipath Effects
    - + Bottom Reflections
  - Distributed Source Characteristic Effects

MULTIPATH CALCULATIONS OF THE ACOUSTIC VERTICAL DIRECTIONAL SPECTRA

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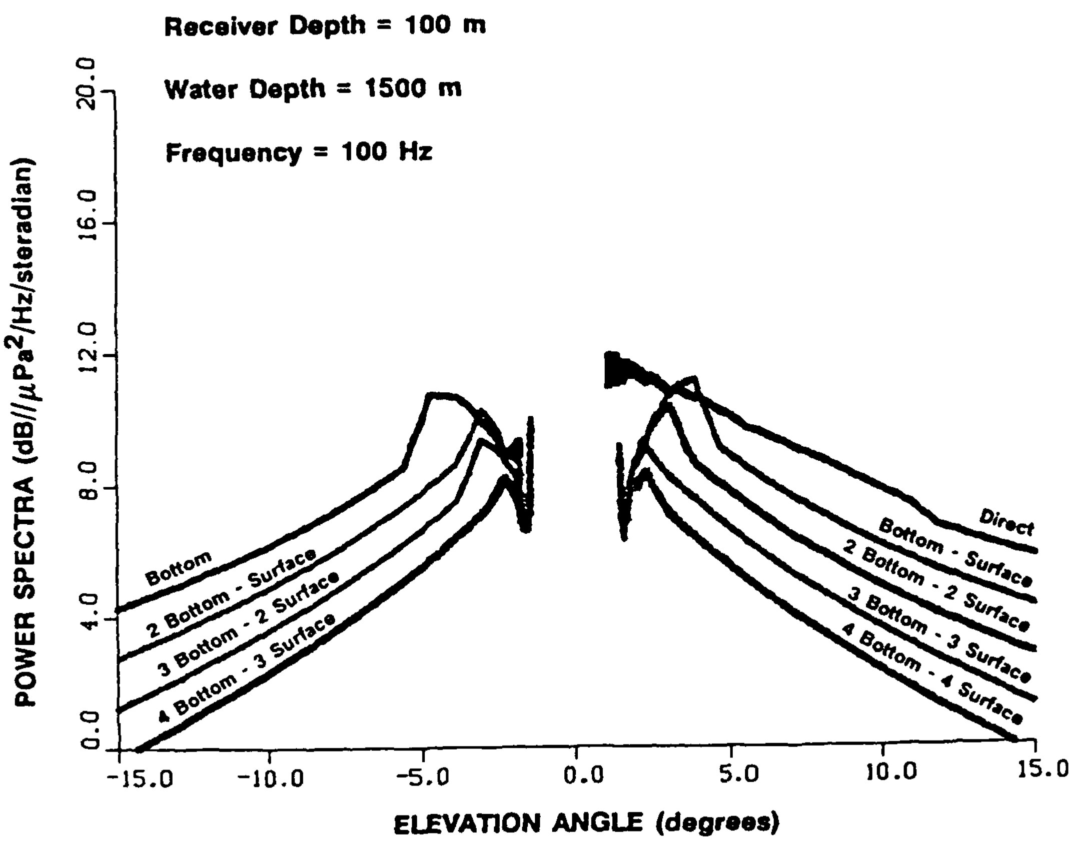
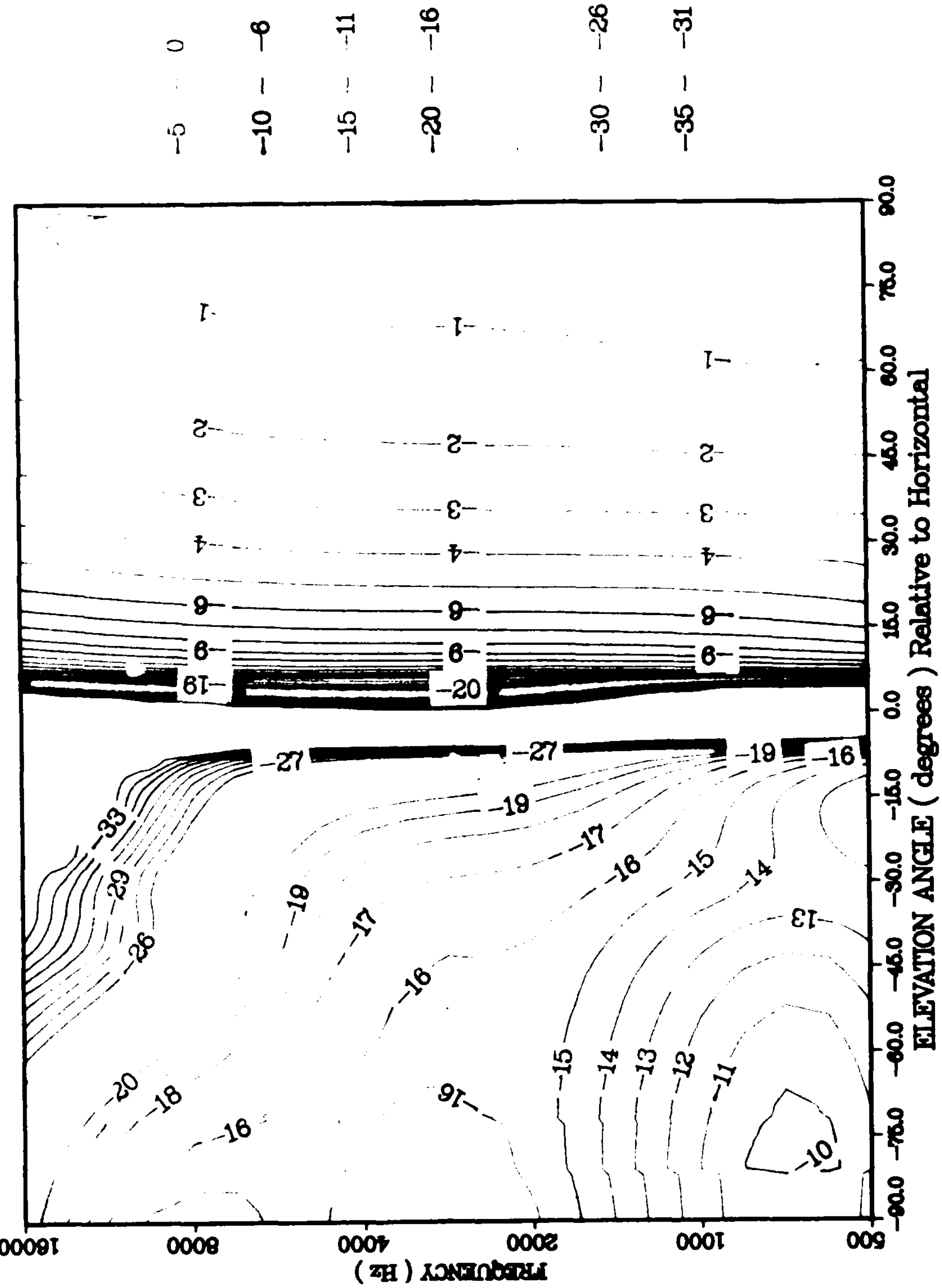
Contributions of Various Multipaths to the Vertical Ambient Directivity Spectra of a Monopole Source Model



Directivity Spectra of a Dipole Source Model, Summer SVP
Receiver Depth = 100 m
POWER SPECTRA (dB//μPa²/Hz/steradian)



Multipath Calculation of the Acoustic Vertical Directional Spectra

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Multipath Calculation of the Acoustic Vertical Directional Spectra

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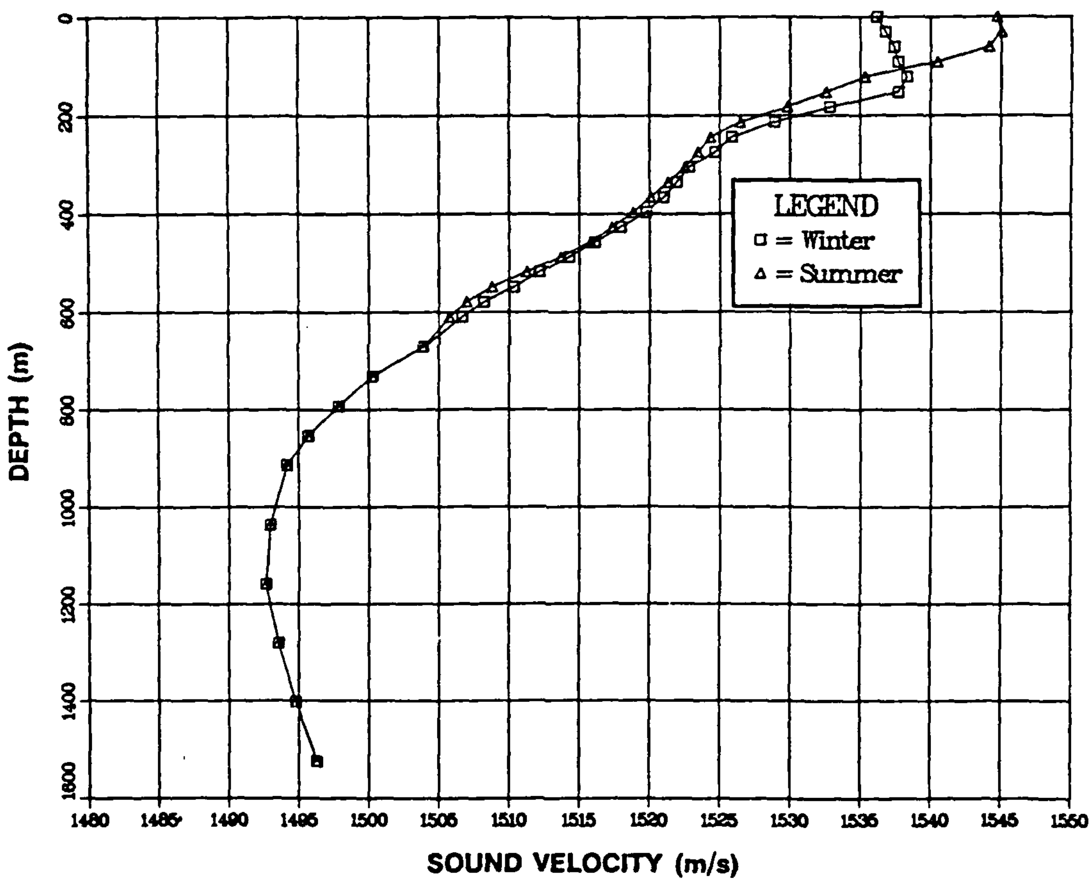
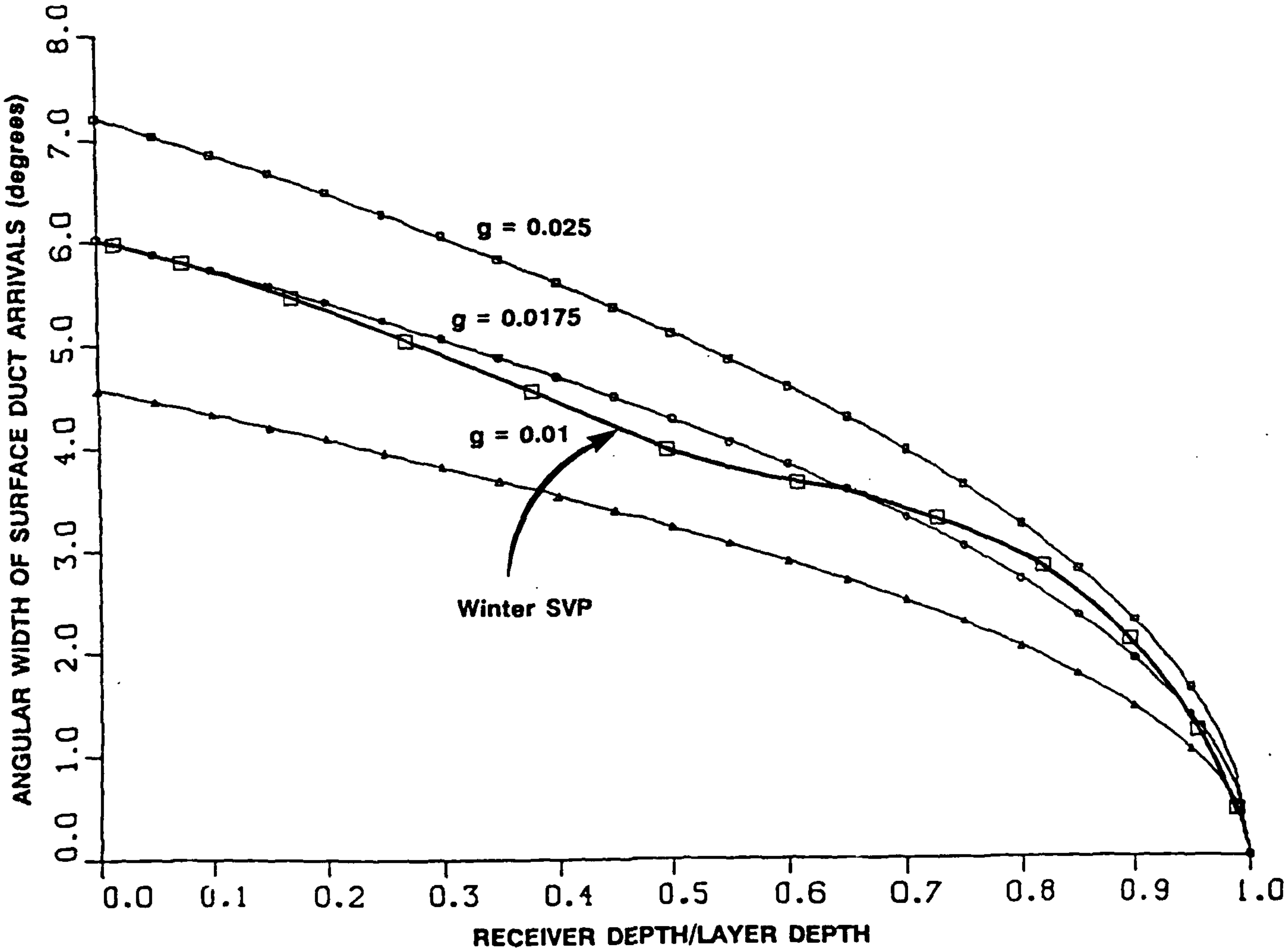
  - Sound Velocity Depth Effects
    - Surface Duct
    - Thermocline Position
  - Multipath Effects
    - Bottom Reflections
  - Distributed Source Characteristic Effects

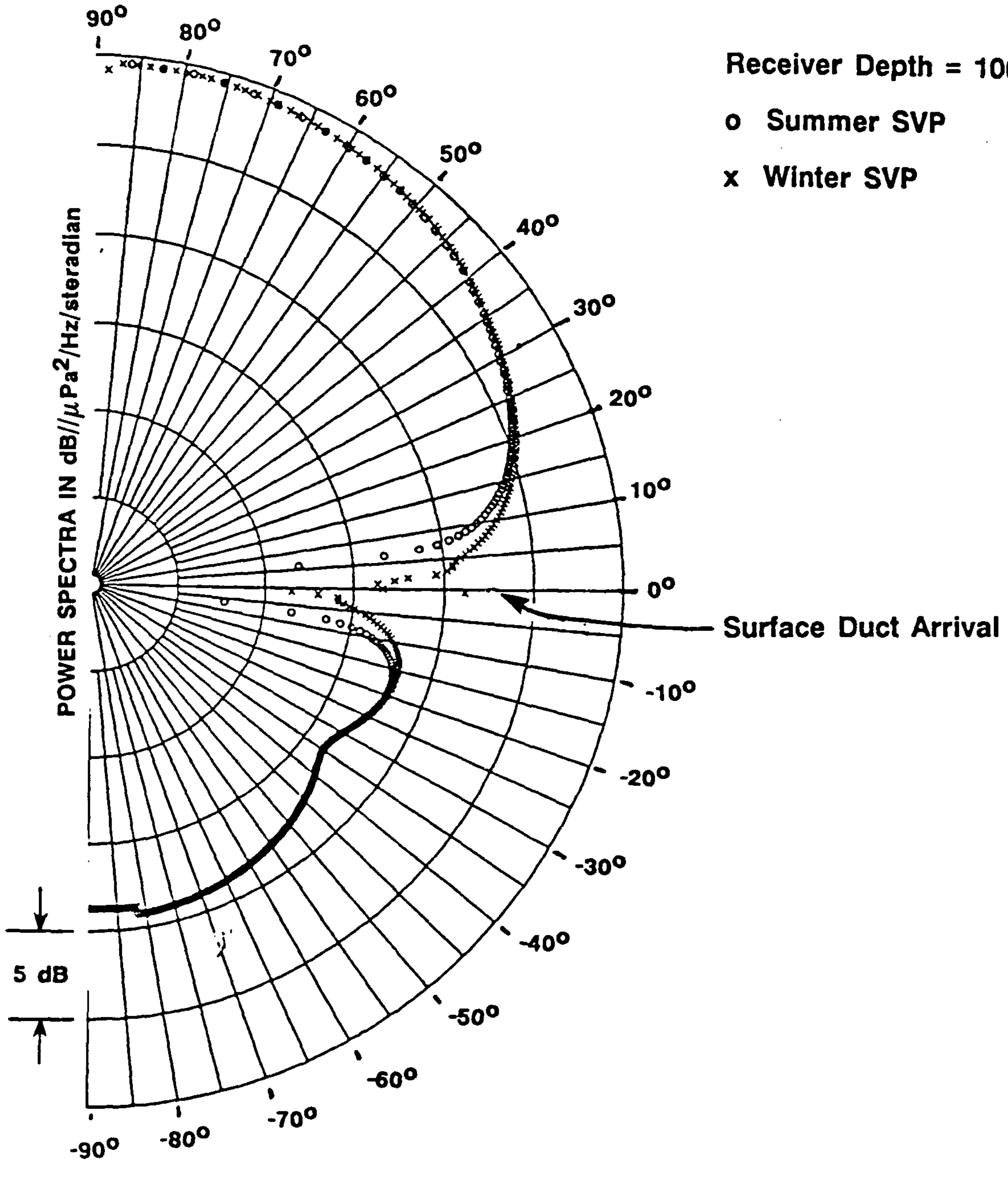
Sound Velocity-Depth Profiles of TOTO



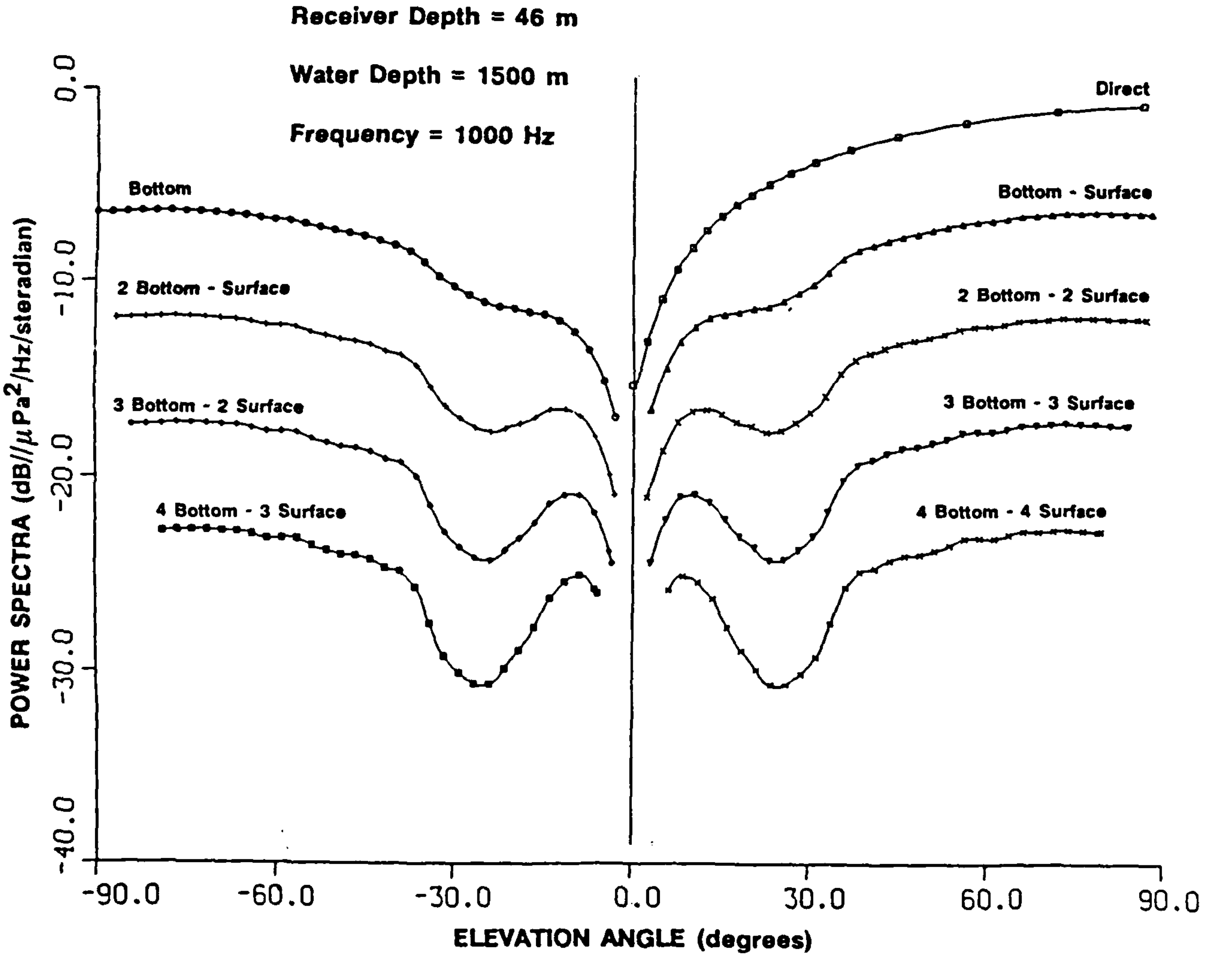
Beamwidth of Ducted Rays



Seasonal Changes in the Vertical Ambient Directivity Spectra of a Dipole Source Model

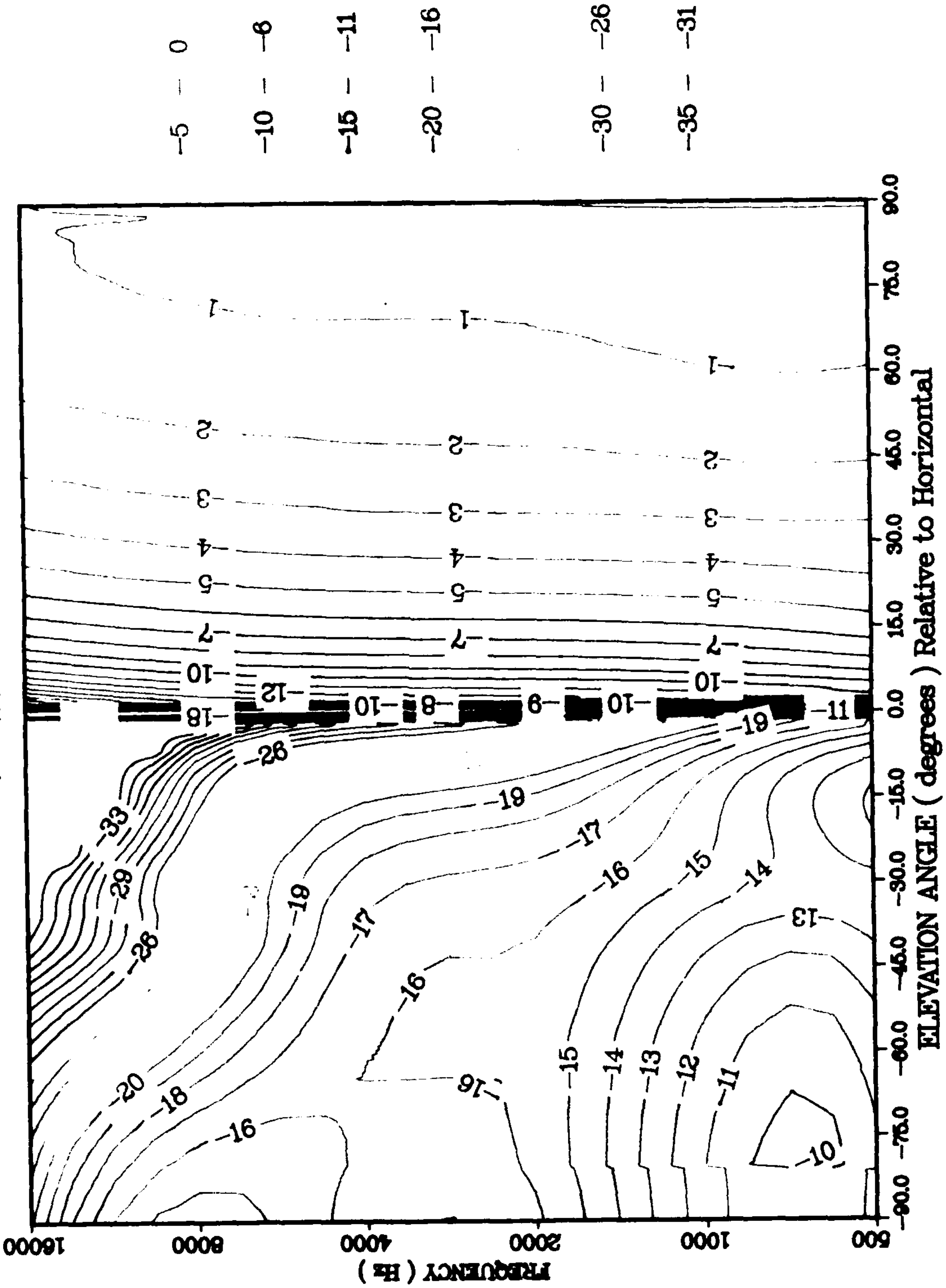


Contributions of Various Multipaths to the Vertical Ambient Directivity Spectra of a Dipole Source Model



Directivity Spectra of a Dipole Source Model, Winter SVP
Receiver Depth = 100 m

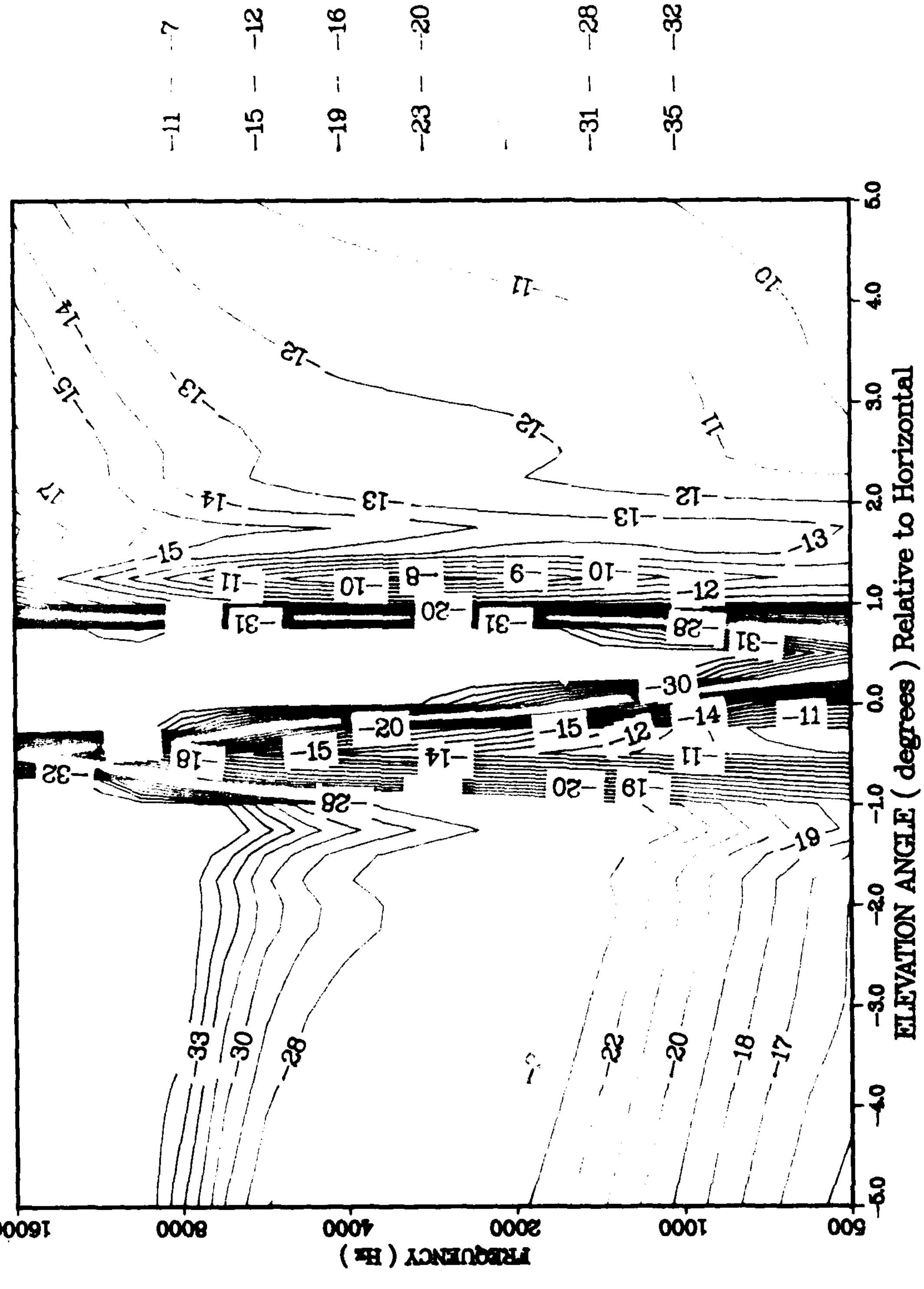
POWER SPECTRA (dB//μPa^2/Hz/steradian)



Shallow–Angle Expansion of Directivity Spectra, Dipole Model, Winter SVP

Receiver Depth = 100 m

POWER SPECTRA (dB//μPa^2/Hz/steradian)



Multipath Calculation of the Vertical Directional Spectra

Directional-Frequency Spectral Derivation

1 - Differential Source Intensity

$$dI_s(\underset{\sim}{x}_s;\ \phi_n') = I_o g^2(\phi')dA(\underset{\sim}{x}_s)$$

where

$\underset{\sim}{x}_s$	Source Location
ϕ'	Source Angle (Vertical) of n^{th} Eigenray
I_o	Homogeneous Source Intensity Density
$g(\ )$	Source Directivity
dA =	$r\ dr\ d\Theta$
Θ	Azimuthal Position of Source Relative to Receiver

2 - Differential Received Intensity

$$dI_r(\underset{\sim}{x}_r,\ \phi_n) = dI_s(\underset{\sim}{x}_s,\ \phi_n')T_n(\underset{\sim}{x}_s,\ \underset{\sim}{x}_r,\ \phi_n', \phi_n)$$

where

ϕ_n	Received Angle (Vertical) of n^{th} Eigenray
$T_n(\ )$	Propagation Loss of n^{th} Eigenray Between Source ($\underset{\sim}{x}_s$) and Receiver ($\underset{\sim}{x}_r$)

Multipath Calculation of the Vertical Directional Spectra

Directional-Frequency Spectral Derivation (Continued)

3 - Directional Spectra Due to n^{th} Eigenray

$$N(\phi_n, \underset{\sim}{x}_r) = \frac{dI_r(\underset{\sim}{x}_r, \phi_n)}{d\psi}$$

where

$$d\psi = d\Theta \; d\phi \; \sin\phi \text{ (differential solid angle)}$$

4 - Assuming Azimuthal Isotropy

$$N(\phi_n, \underset{\sim}{x}_r) = \frac{I_o g^2(\phi_n')T_n(\underset{\sim}{x}_s, \underset{\sim}{x}_r, \phi_n, \phi_n')}{\frac{\sin\phi_n}{r} \; \frac{d\phi_n}{dr}}$$

5 - Directional Spectra

$$N(\phi, \underset{\sim}{x}_r) \simeq \sum_n \sum_m \frac{I_o g^2(\phi_{nm}')T_{nm}[\underset{\sim}{x}_s(m), \underset{\sim}{x}_r, \phi_{nm}', \phi_{nm}]}{\frac{\sin\phi_{nm}}{r_m} \quad \frac{\Delta\phi_{nm}}{\Delta r_m}}$$

where

n, m Subscripts Denote n^{th} Eigenray and m^{th} Range of Source Relative to Receiver

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